Development of a Cryogenic Microwave Filter

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ABSTRACT

The purpose of this UROP project was to design, develop, and install a microwave-frequency filter into a Triton Dilution refrigerator. By the end of the project, a metal-powder filter suitable for such use has been created, and the wiring to install it has been prepared.

MOTIVATION

As electronic devices strive towards size minimization, the necessity of understanding quantum mechanical effects in nanoscale electronic systems has become ever more important. In addition, recently-discovered quantum materials promise new physical properties at low temperatures, making cryogenic quantum electron transport a field of intensive interest.

Microwave thermal noise originating from regions of higher temperature than the sample bath can raise the samples' electron effective temperatures (via broadening of the Fermi-Dirac Distribution) to potentially orders of magnitude higher than the milli-Kelvin sample bath temperature, thereby defeating the purpose taking transport measurements cryogenically. Due to the decoherence caused by microwave noise, low-pass filters are a crucial for many measurements of quantum phenomena at low temperature.

METAL POWDER FILTERS

Background

In contrast to LC and Pi filters, which lose efficiency at high frequency, the metal powder filter introduced by Martinis et al demonstrates excellent performance at high frequency. Although there are many variations, the fundamental concept is to surround a wire with very fine metal powder. Due to the dominance of eddy currents on high frequency signals, microwave signals are in essence pushed into the surrounding particles, where they experience very high dissipation.

Variations

- Coil filled with copper powder (Martinis et al)
- Stainless Steel powder revealed to have superior attenuation (Milliken et al)
- Faraday-cage encapsulation / box design
- Wires lain on PCB rather than wrapped in a solenoid (Mueller)
- Epoxy/Powder mixture to increase thermalization
- Epoxy type

METHODS

This design is based of the premise of maximizing attenuation while maintaining high thermal conduction, electrical isolation, and durability during thermal cycling.

Signal Wires:

Signal wires were embedded in a PCB, following the method of Mueller et al. This results in a much more compact filter with higher precision characterization than conventional hand-wound method. To maximize the surface area of the wire – and thus the distance the microwave signals would travel through the particles - a meander pattern is used. (*Fig 1.*).

Boxes:

The boxes were gold-plated, low-O2 copper, and encapsulated the PCB with a metal-metal contact, acting as a complete faraday cage. The gold plating serves to improve the thermalization of the filterbox to the fridge. In turn, the Stycast thermalizes the PCB to the filterbox. There are additional sections at the edges of the lids which serve to shield the connectors. (*Figures 2,3*)

Mixture:

Although it serves no purpose in attenuation, epoxy is vital for establishing a strong conduction matrix within the powder to the filterbox.

The epoxy/metal powder mixture was prepared with Stycast2850 epoxy and 44μm Cu powder at a ratio of 30:70. This epoxy and ratio have several optimal factors, including,

- Stycast2850 has good thermal-expansion matching with copper, reducing the chance of internal fracturing during temperature cycling.
- Maximized $_{\text{ratio}}$ of copper powder while maintaining uniform density.

(*Figure 4*)

Wiring

The Triton dilution refrigerator contains 48 wires running to and from the sample. Due to size limitations, a standard pcb has 24 wires (12 on each side). Thus, two series of filtering 24 wire each were used, connected by loom wiring and micro-D connectors. The soldered connections were protected by 3 layers. Namely, GE Varnish, epoxy, and silicone rubber. The first layer of GE Varnish is an excellent thermal conductor, but electrically insulating. It also binds to the wires very well. Epoxy and silicone provide tensile strength when inserting or unplugging connectors and mechanical shock resistance, respectively.

RESULTS

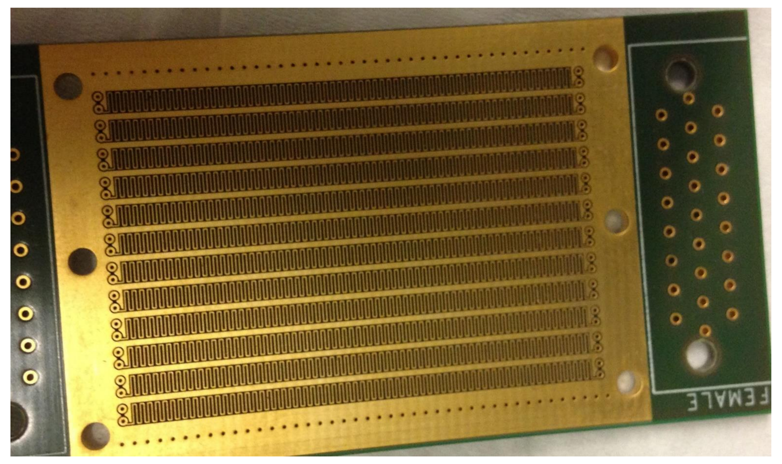

Fig 1. PCB with meander lines. Opposite side is identical.

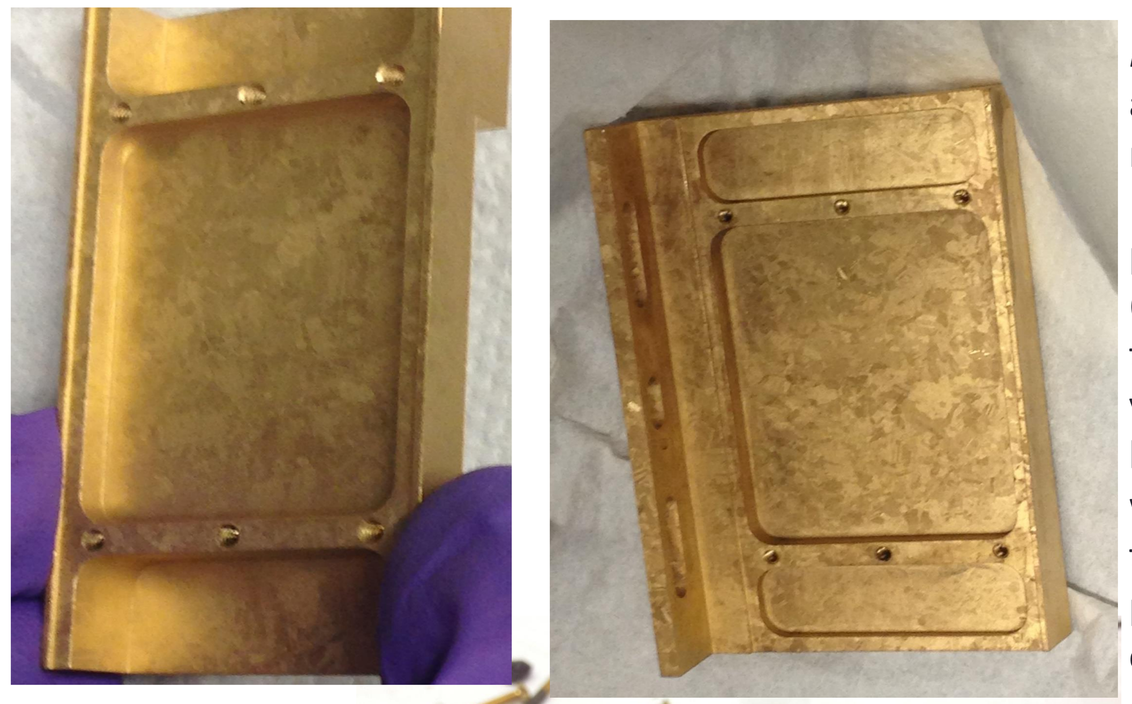

Fig 2, 3. Filterbox lid (left) and main body (right). A PCB rests on either side of the body, with both of its sides prepared with the mixture (as shown below). Note that the small ridges – most visible along the edge of the lid – are less than ½ the width of the pcb, ensuring that the mixture is sealed by pcb-ground to filterbox contact.

Fig 4. Cu-powder/epoxy mixture lain on board. On either side of the pcb, micro-D connectors are visible.

CONCLUSIONS

A cryogenic microwave frequency filter drawing aspects from numerous designs was developed and prepared for installation. It has very high electrical isolation, is fairly compact, and should be resistant to thermal cycles.

Characterization will be performed by temporarily soldering an SMA connector to a line, and analyzing with a scalar network analyzer.

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